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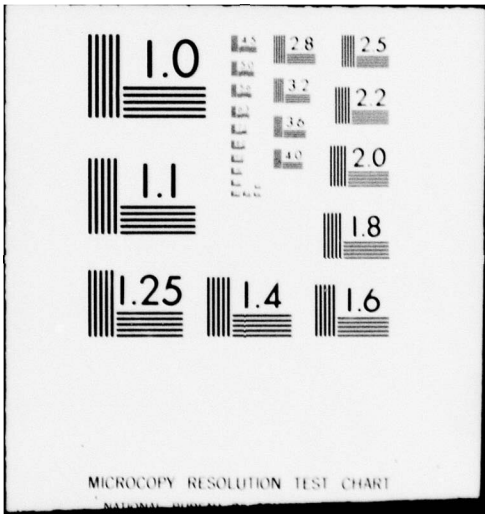
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amcor inc.

800 Follin Lane
Vienna, Virginia 22180

RAMCOR REPORT NO.
U-RC149A-002, c.9

FINAL REPORT ON THE NAVY SATELLITE OCEANOGRAPHIC RESEARCH PROGRAM PLAN

VOLUME II
PROGRAM PLAN DETAILS

18 September 1978

RAMCOR INC.
800 FOLLIN LANE VIENNA, VIRGINIA 22180 (703) 281-1666

18 September 1978

Scientific Officer, Code 222
Director, Sensor Technology Programs
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

Attention: CDR Edward J. O'Brien

Reference: ONR Contract No. N00014-77-C-0320

Subject: Final Report

Enclosed is the following final report on the referenced ONR contract:

RAMCOR Report U-RC149A-002
Final Report on the Navy Satellite Oceanographic
Research Program Plan;
Volume I - Executive Summary
Volume II - Program Plan Details.
18 September 1978

The submission of this final report satisfies the requirements of the contract. The distribution of the report follows Enclosure Number 1 under the Unclassified/Limited category along with additional copies to you and NORDA.

Should you have any further questions, please contact me or Mr. Frank Augustine at the number listed above.

Sincerely,

Victor J. Lujetic

Victor J. Lujetic
Vice President

VJL:bem
Enclosure: RAMCOR Report U-RC149A-002 (3 copies)

cc: ACO, DCAS, 300 E. Joppa Road, Towson, Md. 21204 (1 copy - letter only)
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DDC, Bldg. 5, Cameron Station, Alexandria, VA 22314 (2 copies)
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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER U-RC149A-002	2. GOVT ACCESSION NO	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Final REport on the Navy Satellite Oceanographic Research Program Plan Volume I - Executive Summary Volume II - Program Plan Details		5. TYPE OF REPORT & PERIOD COVERED Program Plan 6. PERFORMING ORG. REPORT NUMBER U-RC149A-002
7. AUTHOR(s) Frank J. Augustine Victor J. Lujetic		8. CONTRACT OR GRANT NUMBER N00014-77-C-0320
9. PERFORMING ORGANIZATION NAME AND ADDRESS RAMCOR, Inc. 800 Follin Lane Vienna, Virginia 22180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217		12. REPORT DATE 18 September 1978 13. NUMBER OF PAGES Vol. I - 38; Vol. II - 47
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) N/A This document has been approved for public release and sale; its distribution is unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) N/A		
18. SUPPLEMENTARY NOTES N/A		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Environmental Remote Sensing Oceanographic Research Satellite Program Plan Satellite Remote Sensing Systems		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this document is to define the Navy operational and R&D requirements for oceanographic/marine atmospheric data as they derive from or relate to the fulfillment of Navy missions and warfare tasks. Having defined the requirements and objectives, this document further strives to relate these needs to the current and projected technical program of the U.S. Navy in the area of satellite remote sensing, to determine their adequacy and to suggest changes needed (if any) to guarantee that Navy and Marine Corps priority needs are met. This program plan will serve as a single technology and management reference for implementation and planning of Navy related satellite programs.

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RAMCOR Report No.
U-RC149A-002

FINAL

REPORT ON THE NAVY

SATELLITE OCEANOGRAPHIC RESEARCH PROGRAM PLAN

Date of This Final Report	18 September 1978
Contract Number:	N00014-77-C-0320
Date of Contract:	1 January 1977
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This research was sponsored and monitored by the Office of Naval Research under ONR Contract No. N00014-77-C-0320

(6) FINAL REPORT ON THE NAVY

SATELLITE OCEANOGRAPHIC RESEARCH PROGRAM (SOREP) PLAN

VOLUME II: PROGRAM PLAN DETAILS

(11) 18 Sep 78

By

(10) Frank J. Augustine
Victor J. Lujetic

(14) 4-RC 149A-002-VOL-2

For

NORDA
NSTL Station, Mississippi 39529

(15) N00014-77-C-0320 (9) Final repts

(12) 49 p.

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TABLE OF CONTENTS

VOLUME I - EXECUTIVE SUMMARY

VOLUME II - PROGRAM PLAN DETAILS

APPENDICES

Appendix A

NAVY MISSION AND TASK DESCRIPTIONS

- Strategic Sea Control - Sea Based Deterrent. Ballistic missile submarines provide the Navy with exceptional strategic deterrent and retaliatory force capability. These forces can conduct sustained operations in ocean areas, including polar regions, while hidden from enemy detection systems. Their great capacity to survive attack ensures the inevitability of severe retaliation in spite of the enemy's first strike effectiveness.

- Tactical Sea Control

  -- Anti-Air Warfare. Anti-air warfare is conducted against aircraft and/or missiles and their supporting forces and operating bases. It comprises all of the measures that are employed in achieving air superiority. In active AAW operations, the enemy's air and missile threat is destroyed or reduced to an acceptable level through the use of fighter aircraft, bombers, antiaircraft guns, surface-to-air and air-to-air missiles, and electronic countermeasures (ECM). Passive AAW operations include all of the measures (other than active AAW measures) that are taken to minimize the effects of hostile air actions. These include cover, concealment, deception (including electronic) and mobility. Technical improvements since World War II in guided missiles, high-speed aircraft, active and passive electronic warfare (EW) equipment, and long range sensors have had a major effect on anti-air warfare. They changed the nature of the threat to naval forces and required radical changes in force defensive measures. Carrier-launched interceptors and surface-to-air missiles are the chief means of defense against aircraft and missile threats. Shipboard anti-aircraft guns are still useful against low and/or slow flying aircraft and may score hits on close-in missiles. They should not be ignored in AAW planning.

  -- Anti-Submarine Warfare. Anti-submarine warfare is conducted against enemy submarines and their supporting forces, operating bases and building yards. The aim of anti-submarine warfare is to deny to the enemy the effective use of his submarines. The enemy submarine presents a most serious threat to the ability of the Navy to gain and maintain control of the seas and defend the United States against attack from the seas. Developments in nuclear power, ballistic missiles, and cruise missile submarines have greatly exacerbated this crucial problem. This threat has been countered by developing balanced ASW forces, including ships, aircraft, submarines and fixed units, for separate or combined operations.

  -- Anti-Ship Warfare. Anti-ship warfare is concerned with the destruction or neutralization of enemy surface combatants and merchant ships, their operating bases and building yards. Its aim is to deny the enemy the effective use of his surface warships and cargo carrying capacity.

-- Mine and Mine Countermeasures Warfare. Mine warfare is the strategic and tactical use of naval mines and mine countermeasures. It consists of mining operations and mine countermeasure operations. Mining operations embrace all of the methods whereby damage may be inflicted on enemy vessels or enemy sea operations hindered by the use of mines. Mining can effectively destroy enemy submarines and other combatant ships, disrupt their operations, destroy or disrupt vital enemy shipping, or defend United States and allied shipping. It may also be used for disrupting enemy shipping routes or as a measure to delay the enemy in sortie. By restricting and delaying an enemy's movements, the actual or possible presence of mines may deprive an enemy of the elective use of more shipping than he loses through mine sinkings. Mines may also be used to deny a shallow water haven to hostile submarine operations. Mining countermeasures operations embrace all of the methods which may be used to counter the threat of an enemy mining effort. Emphasis on mine countermeasures stems from the fact that a vigorous mining campaign, even when carried out by a weak maritime power, may seriously affect the operations of the most powerful of fleets. A well-planted enemy minefield is as potentially dangerous as a hostile naval task force. On the other hand, the successful detection and clearance of a single enemy minefield can influence the outcome of an entire campaign. There are three types of mine countermeasures--area clearance, mine hunting and protective measures.

- Power Projection Ashore

  -- Amphibious Warfare. An amphibious operation is an attack, launched from the sea by naval forces and by landing forces embarked in ships or craft, to achieve a landing on a hostile shore. Amphibious warfare integrates virtually all of the types of ships, aircraft, weapons and landing forces in a concerted military effort against a hostile shore. The essential usefulness of an amphibious operation stems from its mobility and flexibility. The salient requirement of an amphibious operation is the building up of combat power ashore from an initial zero capability to full coordinated striking power as the attack drives toward its final objectives.

  -- Strike Warfare. The broad objective of a naval strike force is the destruction or neutralization of an enemy target or target complex at sea or on land. Naval strike forces may also be used as a deterrent force or a stabilizing influence to prevent the outbreak of hostilities. If hostilities should occur, the strike force is ready for prompt movement and action whenever and wherever required. The various types of strike forces include attack carrier, surface action and submarine strike forces. These forces may operate independently during the period of their organization or may operate in coordination with another force.

  -- Special Warfare. Special warfare involves naval operations generally accepted as being non-conventional in nature, in many cases clandestine in character. In its prosecution specially trained forces are assigned to conduct special mobile operations, unconventional warfare, coastal and river interdiction, beach and coastal reconnaissance, and certain tactical intelligence operations.

- Mission Support

  -- Ocean Surveillance. Ocean surveillance operations obtain and disseminate information about an enemy. They are of great importance in naval warfare because they provide the surveillance that is required for friendly or own control of the seas. Information on the location and movement of enemy shipping, naval forces and all enemy forces which threaten sea communication lines is an immediate requirement in establishing control of the seas at the outbreak of hostilities. While intelligence agencies aid in this task, major reliance must be placed on those surveillance operations that cover vital areas of the seas. Surveillance operations include search, patrol, tracking and reconnaissance and may be conducted by aircraft, surface ships, submarines and satellites. In particular, reconnaissance operations obtain information on the activities and resources of an enemy or collects meteorologic, hydrographic, geographic or electronic information that relates to a particular area. Since reconnaissance missions should not pinpoint the area under surveillance as one in which future operations are planned, they should be conducted either as a part of widespread activity or with routine regularity over a long period of time.

  -- Command, Control, and Communications. Command, control and communications is concerned with the overall operational management of the Navy in peace and war. The Navy Command and Control System (NCCS) provides the means to effectively exercise the operational direction of naval forces. The objectives of NCCS are to ensure that the National Command Authorities, unified commanders, naval component commanders, and subordinate naval commanders are able to discharge their individual responsibilities by receiving sufficient, accurate and timely information on which to base their decisions and by having available the means to communicate these decisions to the forces involved. Effective control over its forces allows the Navy to operate on a coordinated basis in fulfilling its worldwide operational responsibilities.

  -- Support and Logistics. Support and logistics operations are actions taken by one force to aid, protect, complement or sustain another force in the accomplishment of its mission. The major types of support and logistics operations are ASW support operations, air covering operations, naval support of land operations and mobile logistic support operations. These types are usually provided by units of a naval force. For example, an amphibious task group may be supported by an ASW task group against an enemy submarine threat, by a carrier strike group against an enemy air or missile threat, and by a mobile logistic group for providing the necessary supplies for sustained combat operations. Logistics replenishment is the resupply of combat consumables to combatant forces in the theater of operations. It may often be a major factor in determining the success or failure of an operation. A principal aim of naval logistics is to make the operating forces as independent as possible of overseas bases. Most

movement of supporting supplies to engaged U.S. naval forces and to all other U.S. combatant and allied forces is by sealift. U.S. sealift forces are composed primarily of ships of the Military Sealift Command, various ships held in reserve for defense employment, and ships provided from the U.S. Merchant Marine.

-- Personnel/Medical. This personnel/medical support function is concerned with the administration of activities dealing with naval personnel and with safeguarding the health of naval personnel.

APPENDIX B

SOREP PROGRAM DESCRIPTION

The overall goal of this Navy Satellite Oceanographic Research Program (SOREP) is to develop and demonstrate the effective use of satellite remote sensors in oceanographic research and in prediction for Naval operations. The R&D objectives which must be addressed to accomplish this overall goal are to demonstrate satellite sensing utility for determining and predicting:

I. Surface winds

II. Sea surface directional spectra

III. Oceanic thermohaline structure to depths of acoustic detection significance

IV. Coastal conditions of inshore warfare significance

V. Arctic ice conditions

VI. Other related research

Table B-1 summarizes these objectives in priority order and the following thirty-two program elements in group weighed priority order.

1. Environmental Remote Sensing to Develop Sensors, Methods, and Display Techniques
2. Satellite Radar Altimetry
3. Environmental Remote Sensing to Determine Necessary Remote Sensors and Technique
4. Remote Ocean Surface Measurement System (ROMS)
5. SEASAT A Open Ocean Verification
6. Synthetic Aperture Radar Oceanographic Analysis
7. Signal Processing of Satellite Imagery for Oceanographic Information
8. Wave Spectra and Surf Dynamics
9. HF Radar Spectral Analysis for Remote Sea Sensing
10. Microwave Forward Scattering from the Ocean at Grazing Incidence
11. Microwave Forward Coherent and Incoherent Scatter from the Ocean
12. Delta-K Radar Development Program
13. Interactions Among Surface Water, Internal, and Electromagnetic Waves
14. Remote Synoptic Measurement of Sea Surface Currents
15. Sea Spectra Analysis for Wave Height Measurement

TABLE B-1

OBJECTIVES AND PROGRAM ELEMENTS FOR THE NAVY SATELLITE OCEANOGRAPHIC RESEARCH PROGRAM

	NO.	TITLE
PROGRAM ELEMENTS	1	Environmental Remote Sensing to Develop Sensors, Methods, and Display Techniques
	2	Satellite Radar Altimetry
	3	Environmental Remote Sensing to Determine Necessary Remote Sensors and Technique
	4	Remote Ocean Surface Measurement System (ROMS)
	5	SEASAT A Open Ocean Verification
	6	Synthetic Aperture Radar Oceanographic Analysis
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	10	Microwave Forward Scattering from the Ocean at Grazing Incidence
	11	Microwave Forward Coherent and Incoherent Scatter from the Ocean
	12	Delta-K Radar Development Program
	13	Interactions Among Surface Water, Internal, and Electromagnetic Waves
	14	Remote Synoptic Measurement of Sea Surface Currents
	15	Sea Spectra Analysis for Wave Height Measurement
	16	Water and Air Mass Properties and Dynamics
	17	Environmental Sensor Assessment (Classified Project)
	18	Ocean Thermohaline Distribution from Satellite Remotely Sensed Data
	19	Water Vapor Corrections in the Thermal IR
	20	Advanced Retrieval of Atmospheric Mass and Moisture Profiles
	21	Remote Ocean Subsurface Temperature Profiler (ROSTEP)
	22	Oceanographic Exploitation of Satellite Data
	23	Bathemetry and Coastal Topography
	24	Identify, Track, and Predict Iceberg Drift
	25	Satellite Observations to Support Arctic Environmental Studies and Ice Prediction
	26	Satellite Remote Sensing for Snow and Ice Cover Over Land
	27	Satellite Altimeter Oceanographic Analysis
	28	Multi-Spectral Remote Sensing of Atmospheric Constituents
	29	Advanced Sensors for Atmospheric Temperature and Moisture Profiles
	30	Position Determination of Satellite Remote Sensor Data
	31	Interactive Graphics Display for Navy Environmental Requirements
	32	Systems Upgrade for the SMQ-10 and TMQ-29

	OBJECTIVES					
	DEMONSTRATE SATELLITE SENSING UTILITY FOR DETERMINING AND PREDICTING:					
	I	II	III	IV	V	VI
	SURFACE WINDS	SEA SURFACE DIRECTIONAL SPECTRA	OCEANIC THERMOHALINE STRUCTURE	COASTAL CONDITIONS FOR INSHORE WARFARE	ARCTIC ICE CONDITIONS	OTHER RELATED RESEARCH
Display Techniques	X	X	X	X	X	
	X	X	X	X	X	
sors and Technique	X	X	X	X	X	
	X	X	X	X	X	
	X	X	X			
	X	X	X			
nation	X	X	X			
	X	X		X		
	X	X			X	
	X	X				
	X	X				
	X	X				
Waves	X	X				
		X	X			
		X				
			X	X		
			X	X		
Data			X			
			X			
			X			
			X			
			X			
				X		
				X		
nd Ice Prediction				X		
						X
						X
les						X
						X
s						X
						X

16. Water and Air Mass Properties and Dynamics
17. Environmental Sensor Assessment (Classified Project)
18. Ocean Thermohaline Distribution from Satellite Remotely Sensed Data
19. Water Vapor Corrections in the Thermal IR
20. Advanced Retrieval of Atmospheric Mass and Moisture Profiles
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30. Position Determination of Satellite Remote Sensor Data
31. Interactive Graphics Display for Navy Environmental Requirements
32. Systems Upgrade for the SMQ-10 and TMQ-29

Each of these program elements has a particular strategy and time-framed tactics associated with it, which are fully described in this Appendix B. This approach has been taken to indicate the manner in which each program element and objective is expected to be accomplished in order to achieve the goals of the SOREP.

1. ENVIRONMENTAL REMOTE SENSING TO DEVELOP SENSORS, METHODS, AND DISPLAY TECHNIQUES

Strategy

Operational commanders can improve mission effectiveness by exploiting environmental intelligence only when the environmental parameters are quantified and provided in a timely and deterministic manner and in a useable format. The purpose of this effort is to develop sensors, analysis methods, and display techniques for improved command support.

Theoretical studies and field measurements will be carried out to establish analysis techniques for the determination of oceanographic parameters from interaction of electromagnetic waves with the sea surface. Sensors will be developed and their performance evaluated to confirm that their measured outputs do quantify the sea surface parameter to the accuracy and precision necessary for Navy needs.

Tactics

- FY-78
  - -- Complete fabrication of a 140 GHz high-frequency radiometer to evaluate sensor capability for the measurement of oceanographic, meteorological, and coastal parameters in support of Electro-Optical Meteorology (EOMET) and Marine Corps coastal requirements.
  - -- Conduct scanning pulse-limited radar measurements and sensor configuration Surface Contour Radar to define system performance requirements to meet EOMET and Marine Corps coast measurement objectives from aircraft, remote-piloted vehicles and satellites.
  - -- Initiate new theoretical and engineering design studies for remote sensing measurements based on recommendations of the Navy Environmental Remote Sensing Coordinating and Advisory Committee (NERSCAC).
  - -- Conduct remote sensing experiments and data analysis in conjunction with other planned oceanographic experiments and Navy exercises to refine data requirements and evaluate sensor performance models (ETF and pulse-limited radar) to meet Navy measurement objectives. Specific environmental parameters include measurement of marine boundary layer profiles of temperature, humidity, and index of refraction to meet anticipated EOMET requirements for support of advanced weapons systems.

- FY-79

  -- Develop a 100-300 GHz high-frequency microwave spectrometer for measurement of oceanographic, meteorological, and coastal parameters in support of EOMET and Marine Corps requirements. The measurement emphasis will be on high-resolution passive microwave signatures for high-precision determination of such environmental parameters as vertical profiles of atmospheric species composition.

  -- Continue remote sensing experiments and data analysis in conjunction with other planned oceanographic experiments and Navy exercises to evaluate performance models for merging sensor technology and to refine data requirements to meet Navy research and operational measurement objectives.

  -- Establish feasibility of using a 55 GHz-94 GHz high-frequency radar in coherent and scanning modes to measure the three-dimensional ocean surface topography using interferometric techniques and determine vertical atmospheric pressure profile from pressure-broadening of molecular resonance of atmospheric compositional species, such as oxygen.

- FY-80

  -- Develop a 220 GHz passive microwave spectrometer to extend environmental signature measurements. Measurements conducted under this effort using the 90 GHz, 140 GHz, and 220 GHz radiometers and microwave spectrometer are complementary to on-going NASA projects that are investigating the 94 GHz, 115 GHz, and 183 GHz portions of the passive microwave spectrum.

  -- Initiate airborne field measurements experiments using a 55 GHz-94 GHz high-frequency radar in coherent and scanning modes.

2. SATELLITE RADAR ALTIMETRY

Strategy

The purpose of this research is to improve the performance of satellite radar altimeters in order to obtain higher spatial resolution gravity data for all ocean areas. A more accurate geoid and improved gravity data will permit more accurate ballistic trajectories resulting in smaller CEP's for SLBM's as well as corrections to inertial devices resulting in less navigational errors, both in velocity and position.

The approach envisioned is to analyze available NASA satellite radar altimetry data for a variety of environmental and oceanographic conditions to establish the algorithms necessary to determine the height with a precision better than 10 cm. The algorithms will then be implemented in an airborne adaptive radar system to test the validity of the algorithms. Utilizing these proven algorithms for data processing in space will permit a significant cost reduction in the data analysis. Finally, an adaptive radar system will be developed as the baseline system for an ultimate commitment to space.

Tactics

- FY-78
  - -- Analyze high-bit rate GEOS-3 data to establish the algorithms necessary for routine processing of GEOS-3 data over long flight paths for determining the geiod spectral analysis.
  - -- Establish the error contributions of GEOS-3 radar altimeter height measurements by comparing overlapping passes.
  - -- Design the algorithms for a special ground to process SEASAT data.
  - -- Begin operational flights of the advanced radar system.
- FY-79
  - -- Complete special ground processors for reducing SEASAT radar altimeter data.
  - -- Complete the interface of the advance radar system with the on-line computer.
  - -- Develop the software processing for using the on-line computer to minimize the data processing and handling in an ultimate radar system.
  - -- Establish the environmental corrections necessary for the improved precision measurements.
- FY-80
  - -- Continue underflights of SEASAT for the necessary ground truth data.
  - -- Compare SEASAT altimeter data with GEOS-3 data along with the aircraft ground truth data results for improvement in the processing of SEASAT data.

3. ENVIRONMENTAL REMOTE SENSING TO DETERMINE NECESSARY REMOTE SENSORS AND TECHNIQUES

Strategy

The strategy for this research is to experimentally determine the necessary remote sensors and techniques that are applicable for improving oceanographic monitoring and prediction. These remote sensing studies will be coordinated with the objective of satisfying Navy Environmental Remote Sensing Program needs. The FY-78 and FY-79 efforts are directed toward the Navy Operational Requirement for Satellite Measurement of Oceanographic Parameters.

In addition, electromagnetic sensors, both passive and active, will be utilized to determine quantitatively the accuracies with which sea surface temperature, surface winds, wave heights, topography and other sea surface parameters can be measured to insure that the measurements and techniques are fulfilling NERSP's needs.

Tactics

- FY-78
  - -- Conduct aircraft measurements with the ROMS passive microwave sensor (PMS) simulator to evaluate predictions to extended ROMS capabilities analyses and to serve as the ground truth for the evaluation of ROMS PMS algorithms using SMMR data.
  - -- Conduct extended ROMS capability analyses for measurement of precipitation and soil moisture and incorporate these results in the ROMS PMS/Space Test Program (STP) plan and data analysis.
  - -- Analyze radar data from the scatterometer, altimeter, and imaging radar from SEASAT to compare sensor performance with predictions of theoretical studies and engineering parameter comparisons.
  - -- Conduct aircraft flight measurements with the NRL adaptive radar for comparison with theoretical studies and engineering parameter comparisons and to serve as ground truth for satellite radar data analysis.
- FY-79
  - -- Complete ROMS PMS simulator aircraft measurements needed for ground truth to evaluate ROMS PMS algorithms using SMRR data.
  - -- Complete analysis of SEASAT active microwave sensors for evaluation of ROMS Active Microwave Sensor (AMS) performance prediction models.
  - -- Complete aircraft flight measurements with NRL Adaptive Radar necessary for ROMS AMS tradeoff analysis.
  - -- Conduct sensor performance trade-off analysis for recommendation of candidate ROMS AMS sensor.
  - -- Define sensor for transition to ROMS AMS/STP experiment.

- FY-80

  -- Complete preliminary ROMS PMS data reduction algorithms for transfer to FNWC.

  -- Define data reduction algorithms for 5D-2 SSM/I for transfer to FNWC.

  -- Complete aircraft flight experiments using modified NRL adaptive radar to develop data processing algorithms for ROMS AMS.

  -- Perform data analysis trade-off studies for on-board/on-ground data processing procedures for ROMS AMS/STP experiment.

4. REMOTE OCEAN SURFACE MEASUREMENT SYSTEM (ROMS)

Strategy

The purpose of this research is to develop passive and active microwave sensors for implementation within the DMSP to meet Navy requirements for oceanographic measurements from satellites.

The multifrequency PMS will be utilized to measure sea surface temperature, sea surface winds, sea ice cover, and atmospheric parameters to meet Navy requirements. A prototype PMS sensor will be fabricated to evaluate performance within the STP, develop specifications for an operational sensor for implementation within DMSP, and provide quasi-operational data for utilization by FNWC.

Tactics

- FY-78

  -- Complete design studies for antenna options and feed techniques.

  -- Perform system and cost trade-off analysis and select an antenna.

  -- Develop an experiment plan and identify the launch vehicle. This effort will be done in cooperation with NSSA, STP, FNWC, OP-945, CP-986, and NAVAIR.

  -- Freeze ROMS PMS sensor design.

  -- Develop STP mission plan. This includes the final definition of orbit, launch vehicle assignment, downlink data techniques, preliminary test and evaluation plan, and the role of major participants such as NSSA, STP, DMSP, FNWC, NRL, and NEPRF.

- FY-79
  - -- Perform engineering designs for ROMS STP antenna.
  - -- Perform engineering design for ROMS STP radiometer.
  - -- Perform system design for modifications necessary for ROMS STP/ DMSP downlink and analysis.
  - -- Develop data package that include engineering specifications for sensor fabrication bid request.
  - -- Analyze SMMR data received at FNWC for evaluation of ROMS PMS data analyses algorithms.
  - -- Begin specific planning for detailed procedures for sensor test, evaluation, and data processing techniques.
- FY-80
  - -- Begin antenna fabrication.
  - -- Begin radiometer fabrication.
  - -- Begin development of necessary software and data system modifications for ROMS data utilization at FNWC.
  - -- Complete SMMR data analysis for evaluation of ROMS PMS algorithms.
  - -- Detailed planning for development of test, evaluation, and processing techniques.
  - -- Development of Tri-Service plan for DMSP utilization of RMS STP data.

5. SEASAT A OPEN OCEAN VERIFICATION

Strategy

Satellites such as SEASAT have the potential to provide broad scale coverage of such oceanographic parameters as sea surface temperature, directional wave spectrum, surface winds, and ocean currents. However, SEASAT sensors have never been evaluated against precisely determined open ocean physical conditions. This effort will provide precise open ocean ground truth for SEASAT by using FLIP. For the first time the physical relations between microwave cross section and the motion and characteristics of the ocean surface may be determined, enabling the physics of the ocean surface to be better understood.

FLIP will be anchored for several months in the Eastern North Pacific to collect ground truth temperature profiles, three dimensional wave records, currents, and winds during SEASAT overflights. These data will be correlated with passive and active microwave synthetic aperture radar and altimeter satellite observations in order to model the response of the satellite to oceanographic features and understand the physics of the wave-wave interactions in the ocean.

Tactics

- FY-78
  - — Station FLIP in a deep ocean environment.
  - — Run sensor check.
  - — Derive wave-wave and wind-wave models.
  - — Program satellite ocean response models.
- FY-78/79
  - -- Gather ground truth data from FLIP.
  - — Obtain SEASAT sensor data records.
- FY-79
  - — Return FLIP to port.
  - -- Correct satellite-ocean response models.

6. SYNTHETIC APERTURE RADAR OCEANOGRAPHIC ANALYSIS

Strategy

Fleet activities depend upon a capability to forecast surface winds and waves. To improve this capability, it is necessary to look at the basic phenomena near the air-sea interface. The purpose of this research is to evaluate the potential for using satellite borne synthetic aperture radar for remote sensing of surface waves.

Synthetic aperture radar data from SEASAT will be processed to determine the correlation between it and an independently derived theoretical model of radar return for a given ocean surface roughness. Surface roughness conditions will be extracted from data measured at FLIP during satellite overflights. The model verification will lead to an understanding of the physical behavior of capillary waves imbedded in a full spectrum wave field and a model to infer actual wave conditions from SEASAT voltage outputs.

Tactics

- FY-78
  - — Develop an analytic model of synthetic aperture radar returns from travelling surface wave spectra.
  - — Obtain and process initial synthetic aperture radar data from overflights of oceanographic ground truth experiments.
  - — Obtain relevant initial wave spectrum data from oceanographic experiments.

- FY-79
  - -- Test model performance against obtained data.
  - -- Refine model.
  - -- Obtain and process final synthetic aperture radar and oceanographic data.
- FY-80. Test the model for success against new data.

7. SIGNAL PROCESSING OF SATELLITE IMAGERY FOR OCEANOGRAPHIC INFORMATION

Strategy

The purpose of this research is to develop procedures to extract information from high resolution satellite imagery using advanced signal processing techniques. The information includes surface roughness from power spectra of reflected sunlight, location of surface fronts from thermal gradients, and quantification of the structure of the size and characteristic of eddies.

The effort will also involve the development and application of algorithms to remotely sense imagery data using state-of-the-art special function processors in order to extract oceanographic information from these data. Atmospheric phenomena, primarily clouds, will first be eliminated from the data using multichannel thresholding techniques. Significant oceanographic features will then be isolated by examining higher order derivatives of the detailed features of the ocean surface structure as apparent in the digital imagery.

Tactics

- FY-78
  - -- Evaluate existing algorithms for distinguishing cloud cover in satellite imagery using interactive graphics display devices with the array processor.
  - -- Apply higher order derivative enhancement techniques in order to identify thermal fronts and eddies.
  - -- Correct algorithms for classifying spiral cloud patterns for application to thermal eddies.

- FY-79

  -- Continue work using interactive graphics display devices with the array processor and evaluating existing algorithms for distinguishing cloud cover in satellite imagery.

  -- Continue work applying higher order derivative enhancement techniques in order to identify thermal fronts and eddies.

  -- Continue work correcting algorithms for classifying spiral cloud patterns for application to thermal eddies.

  -- Initiate processing of sun-glint patterns using FFT techniques for the delineation of surface roughness characteristics.

- FY-80

  -- Extend the processing of sun-glint patterns using FFT techniques for the delineation of surface roughness characteristics to higher wind speeds.

  -- Verify results on remote sensing ground truth range data.

8. WAVE SPECTRA AND SURF DYNAMICS

Strategy

The basic strategy is to conduct research to determine procedures for the use, enhancement, and interpretation of sea surface radar imagery for determining wave spectra and energy distribution over the Continental Shelf and into the surf zones.

Extensive testing of the dual frequency and dual polarized synthetic aperture radar of the Environmental Research Institute of Michigan will be accomplished by flying these radars at high altitudes over deep water and shallow water waves under extremely varied environmental conditions. Ocean observations and in situ measurements will occur concurrently with these overflights. Appropriate assessments of the effects of scatterer motions on synthetic aperture radar ocean wave images will be made.

Tactics

- FY-78

  -- Develop and fabricate a processor to extract wavelength and direction from the collected data.

  -- Continue flight tests of the synthetic aperture radar.

- FY-79

  -- Concentrate the effort on SAR flight tests. Vary the altitudes with sea state and directions of flight. Experiment with various wavelengths and polarizations.

  -- Complete the processor fabrication.

- FY-80. Complete flight testing and report on criteria for fabrication of modified synthetic aperture radar and data processor.

9. HF RADAR SPECTRAL ANALYSIS FOR REMOTE SEA SENSING

Strategy

The aim is to develop techniques for the extraction of oceanographic and meteorological parameters from Doppler power spectra of HF radar energy backscattered from the sea. These techniques will be applied toward remote sensing operations of an over-the-horizon HF radar collecting data from cells contained in ocean areas over millions of square miles. Both surface and subsurface naval operations can be severely restricted by lack of data from such areas. Thus, comprehensive real-time knowledge of ocean waves is essential for the intelligent application of naval forces.

The SEA ECHO radar on San Clemente Island will be used to collect and analyze 2-degree high azimuthal resolution data in the surface wave mode and to investigate Doppler spectrum statistical variations with azimuth and radar frequency as a function of sea state, for comparison with ionospheric target fading statistics.

Tactics

- FY-78
  - -- Develop a backup on-site capability of raw data taping using existing TOP SEA hardware.
  - -- Develop software for FFT processing of raw data on the new NRL Texas Instruments advanced scientific computer.
  - -- Continue collection, analysis and cataloging multifrequency radar spectra relative to local meteorological conditions and sea spectrum. Types of conditions include long fetch continuous winds, growing wave spectrum, decaying wave spectrum, continuous change of wind direction and speed conditions, and discontinuous change of wind direction and speed.
- FY-79
  - -- Compare data with various theoretical spectrum models, attempting to determine meteorological and oceanographic conditions from radar data. These include wind direction and speed, directional sea spectrum, direction and magnitude of sea currents, and the degree of turbulence in winds and waves.
  - -- Develop techniques for comparison of target amplitude variations with radar clutter statistical variations to improve signal detection capabilities for target signals in clutter.

10. MICROWAVE FORWARD SCATTERING FROM THE OCEAN AT GRAZING INCIDENCE

Strategy

The purpose of this program is to obtain a complete description of the electromagnetic scatter from the ocean as is necessary to determine ocean effects on target detection and identification. Information determined from this program will be used to provide criteria for the design of radar systems operating in clutter limited domains.

Since the present clutter models do not apply to radar systems operating at near-grazing incidents and scattering, the electromagnetic forward scattering problem will be investigated both theoretically and experimentally, especially with regard to the effects of electromagnetic surface wave and leaky wave effects.

Tactics

The representation of a random ocean surface as a sum of sinusoids has been successfully done by many workers. Thus, the analysis of scattering from a simple sinusoidal surface provides basic information on the scattering properties of more complex surfaces. Analyses have been derived for acoustic scattering from soft and hard surfaces. This analysis can be generalized to electromagnetic scattering for TE (soft) and TM (hard) cases. The scattered fields are represented superpositions of plane waves. The scattering coefficients will be found for realistic values of ocean wavelength, ocean wave height, incidence angle, and signal wavelength. Anomalies in the scattering coefficients will be located and related to the Bragg scattering conditions. Computer calculations will be made for the field patterns and grating lobe structure related to the ocean parameters.

11. MICROWAVE FORWARD COHERENT AND INCOHERENT SCATTER FROM THE OCEAN

Strategy

The purpose is to research the electromagnetic wave propagation and scattering by the surface of the ocean and to determine the microwave forward coherent reflection and incoherent scattering from the ocean. This work will include scattering from convective cells over the ocean and the possible coupling effects between the inversion layer and the evaporative layer, as these phenomena may interact with the ocean scattered fields.

Theoretical treatment of forward scattering from the ocean is now being carried out and an experiment is being planned to measure forward coherent reflection and incoherent scattering using nanosecond pulses.

Tactics

This program element will be performed entirely during FY-78 with the following planning and data analysis:

- Reduce and analyze the previous L-band ocean reflection data.
- Report the results in early FY-78.
- Plan the experiment on forward scatter from the ocean surface.
- Perform the experiment and analyze the results.

12. DELTA-K RADAR DEVELOPMENT PROGRAM

Strategy

The purpose of this research is to determine the effectiveness of a coherent dual frequency correlation radar for achieving improved target detection and classification, and to achieve remote sensing of ocean waves and surface currents.

The Delta-K radar transmits two closely-spaced RF frequencies and, upon reception, cross-correlates the coherently detected backscattered fields to achieve improved detection and classification for both fixed and moving ship targets. Improved detection is possible because, although the radar is highly directional, the output has the characteristics of HP return from ships and the sea. In addition, target glint and scintillation effects are reduced and long-term coherent integration of returns is possible.

Tactics

The initial experimental successes using the X and L-band Delta-K radars will be followed by in-depth studies of:

- An experimental determination of the maximum attainable coherent integration time for single and dual-frequency coherent radar operation using simultaneously obtained data. This will be accomplished by the measurement of the S/N+C ratios obtainable for stationary and moving ship targets.
- A theoretical and experimental examination of the effects of multiple ship targets being present in a single radar resolution cell. This will enable the determination of the performance of the radar as a means of classifying target returns.
- Target classification using resonance region returns (radar wavelength ship dimensions). This has been accomplished at the Ohio State Electroscience laboratory but never in the field using non-scaled targets.

- The capability of the Delta-K radar as the primary sensor for a shipboard platform motion predictor. The platform motion predictor would be used to determine future (up to 20 seconds) roll, pitch and heave of a landing pad for helicopters and VSTOL aircraft and would be used to predict safe landing times.

Data collection and analysis will continue with the experimental systems. Cooperative experiments will be run utilizing the Delta-K system and Sea Photo Analysis (SPA). The data from the SPA technique would provide a means of determining the spectrum of the sea itself. This data would then be compared with the spectrum determined by the radar with ultimate objective being to elucidate the effects of longwave and shortwave coupling.

The impact of these studies on radar design and operation in an ocean environment will be further considered. In particular, the possibility of predicting the future displacements of the ocean surface will be analyzed. The testing of a pulsed Delta-K radar will be initiated. This system will incorporate significantly higher power and therefore greater range, improved frequency and time channel separation, improved sea spectral stationarity, and most importantly, the ability to determine target range and utilize a number of range gates.

13. INTERACTIONS AMONG SURFACE WATER, INTERNAL, AND ELECTROMAGNETIC WAVES

Strategy

The purpose of this effort is to determine the dependence of short gravity wave and capillary wave amplitudes on windspeed, currents, surfactants, air-water temperature difference and to develop theories in conjunction with the measurements which will yield quantitative descriptions of the fine structure of the air-sea interface. Such knowledge is necessary for a variety of Naval applications including surveillance of the surface weather over the oceans from satellite and OTH radars for ship routing, especially hydrofoils, to non-acoustic anti-submarine warfare.

Microwave scattering techniques at 1.8 GHz, 4.3 GHz, 9.375 GHz, 23.9 GHz and 70.1 GHz together with optical and photometric methods will be used to measure phase speeds, temporal growth, relaxation rates, and modulations due to straining and Doppler spectra of wind generated waves in wave tanks as well as on the ocean. Wind wave interactions and higher order Bragg scattering calculations will be made and the radiative transfer equations solved for comparison with experimental results. Analytical and numerical solutions of the Orr-Sommerfeld equations will be obtained to yield growth rates and to infer air-sea boundary layer properties from measured phase speeds.

Tactics

- FY-77
  - -- Measure fetch and windspeed dependence of capillary wave directional spectra in a wavetank.
  - -- Repeat selected backscatter modulation measurements at 9.375 GHz in the new wavetank.
  - -- Develop higher order straining theory.
  - -- Determine dependence on short gravity wave phase speeds on wave amplitude.
  - -- Measure modulations of waves up to 30 cm long photometrically on the ocean.
- FY-78
  - -- Measure straining modulations in new wavetank at 1.8 GHz.
  - -- Complete photometric study of short waves on the ocean.
  - -- Develop theory for steady short gravity waves on the ocean.
- FY-79. Measure wind induced growth of seiches.

14. REMOTE SYNOPTIC MEASUREMENT OF SEA SURFACE CURRENTS

Strategy

This research is directed toward the development of a method to determine the temporal and spatial variations of speed and direction of surface water currents by remote synoptic measurements and to determine the feasibility of using line scan imagery of wave fields and their refraction patterns to deduce surface circulation patterns. The feasibility of automated processing of these data for rapid airborne and satellite coastal-ocean reconnaissance will be investigated. The method proposed is to fly a multispectral scanner, optimized for sea surface scanning, at very high altitude. Line scan imagery of ocean swell or inshore waves will be cross-correlated both spatially and temporally for extraction of wavelength, angle, and speed. The evaluation and analysis of the wave relations will produce information on wave characteristic attenuation resulting from current action. In situ ocean data will be obtained simultaneously with the scanner overflight.

Airborne line scan imagery of waves in a specific experiment area will be acquired and related to detailed and concurrent wave data obtained from in situ instruments for precise correlation. These data will be obtained for a variety of sea states and at varying altitudes and flight paths to thoroughly test the system capability.

- Test various atmospheric attenuation correction models for satellite IR data in the Gulf Coast region during the winter season, at which time atmospheric moisture varies significantly with time. Sea state and sea surface temperature measurements are readily available, and water vapor profiles are available from detailed atmospheric soundings.

- Analyze the thermal infrared data along the Gulf Coast from the TIROS-N AVHRR and HRIR, LANDSAT C thermal infrared band 8, the NIMBUS G thermal channel, the Coastal Zone Color Scanner, and the infrared radiometer of the heat capacity mapping mission of the Applications Explorer Mission.

- Test the ability of radiometric and atmospheric corrected satellite data to accurately map sea surface temperatures (both time variations and horizontal gradients) and for evaluation and intercomparison of sensors for detection of coastal oceanographic variability.

Coordinated meteorological and coastal ocean experiments will be conducted in various and specific coastal environments using instrumentation compatible with present satellite sensors and appropriate diagnostic sensors such as radiosonde, acoustic radar, recording thermistors, and weather radar. In situ parametric ground truth measurements will be made simultaneously. The correlated data will be used to formulate meaningful algorithms suitable for determining the significance of similar satellite sensor data.

The experiments will be set up at a convenient and appropriate facility such as NCSL Panama City, Florida or other selected field sites. Coordination of the experiments can include a number of research groups and equipments necessary to adequately complete the exercise. Appropriate reports, instrument verifications, model improvements, and presentations will be made during the course of the program.

Tactics

- FY-78

  -- Develop plans for two complete experiments. One experiment during the winter and the second during the summer.

  -- Fabricate the necessary ocean instrumentation, place the in situ instruments and coordinate aircraft sorties with satellite passes.

  -- Process and analyze the data for sensor correlations with ocean atmosphere features and conditions.

  -- Validate the satellite sensor data and report the results and accomplishments.

- FY-79

  -- Repeat the FY-78 experiments using advanced instrumentation for in situ measurements. One of the two experiments will be in a new coastal environment.

  -- Continue instrument and model development and refinement.

  -- Issue a report on the validity of satellite instrument data, model capabilities, and water and air mass physics and dynamics.

15. SEA SPECTRA ANALYSIS FOR WAVEHEIGHT MEASUREMENT

Strategy

The purpose of this program is to further analyze the remote sensing capabilities of the SPA technique. The SPA technique may be used routinely to sense and measure the state of the ocean surface spectral fluctuations under a wide range of conditions. Success in this effort will result in a new naval method for the determination of major ocean descriptors, which can have a decided impact on naval sensors and systems. This includes the detection of small targets on the ocean and sensing small perturbations of ocean surface features.

SPA techniques are now being applied in the areas of target detection and real time sea state determinations. The present limitations of SPA, such as high obliquity, perspective distortion, long wavelength suppression, and wave sensitivity inaccuracies, will be studied and means for alleviating them investigated.

Tactics

The polarization and relative intensity of direct sunlight and skylight incident upon and reflected from and wind disturbed ocean surface will be investigated further. The results for arbitrary sensor polarizations will also be investigated. The polarization and intensity patterns of light emanating from below the ocean surface, for different sun heights and bearings, camera look angles, and surface roughness, are necessary to completely define the wave visibility function and optimize the procedures for obtaining surface photographs. A cooperative program will be undertaken with the U.S. Army Engineer Topographic Laboratories. The program will determine the applicability of SPA in the detection and localization of submerged topographic features, such as seamounts and shoals, that would be a hazard to navigation. This study would involve changes in the long wave length spectrum of the surface waves in the vicinity of such features.

16. WATER AND AIR MASS PROPERTIES AND DYNAMICS

Strategy

The purpose of this research is to implement and coordinate remote sensing experiments in conjunction with scheduled detailed oceanographic experiments. The research will include definitions of the physical, chemical, and biological characteristics of the Continental Shelf and inshore water and air masses, their rates of change, and directions of migration. The approach envisioned for the proposed research is to:

- Study the processes of transformation of bay, inshore, inner shelf, outer shelf, and adjacent deep waters during outbreak of polar continental air in a series of short, but intensive field measurement experiments.

- Test various atmospheric attenuation correction models for satellite IR data in the Gulf Coast region during the winter season, at which time atmospheric moisture varies significantly with time. Sea state and sea surface temperature measurements are readily available, and water vapor profiles are available from detailed atmospheric soundings.

- Analyze the thermal infrared data along the Gulf Coast from the TIROS-N AVHRR and HRIR, LANDSAT C thermal infrared band 8, the NIMBUS G thermal channel, the Coastal Zone Color Scanner, and the infrared radiometer of the heat capacity mapping mission of the Applications Explorer Mission.

- Test the ability of radiometric and atmospheric corrected satellite data to accurately map sea surface temperatures (both time variations and horizontal gradients) and for evaluation and intercomparison of sensors for detection of coastal oceanographic variability.

Coordinated meteorological and coastal ocean experiments will be conducted in various and specific coastal environments using instrumentation compatible with present satellite sensors and appropriate diagnostic sensors such as radiosonde, acoustic radar, recording thermistors, and weather radar. In situ parametric ground truth measurements will be made simultaneously. The correlated data will be used to formulate meaningful algorithms suitable for determining the significance of similar satellite sensor data.

The experiments will be set up at a convenient and appropriate facility such as NCSL Panama City, Florida or other selected field sites. Coordination of the experiments can include a number of research groups and equipments necessary to adequately complete the exercise. Appropriate reports, instrument verifications, model improvements, and presentations will be made during the course of the program.

Tactics

- FY-78

  -- Develop plans for two complete experiments. One experiment during the winter and the second during the summer.

  -- Fabricate the necessary ocean instrumentation, place the in situ instruments and coordinate aircraft sorties with satellite passes.

  -- Process and analyze the data for sensor correlations with ocean atmosphere features and conditions.

  -- Validate the satellite sensor data and report the results and accomplishments.

- FY-79

  -- Repeat the FY-78 experiments using advanced instrumentation for in situ measurements. One of the two experiments will be in a new coastal environment.

  -- Continue instrument and model development and refinement.

  -- Issue a report on the validity of satellite instrument data, model capabilities, and water and air mass physics and dynamics.

- FY-80. Repeat the FY-79 experiments using additional advanced in situ instrumentation and a new coastal field site to provide additional and varied environmental conditions for sensor validation.

17. ENVIRONMENT SENSOR ASSESSMENT

This is a classified project and the details will not be covered here.

18. OCEAN THERMOHALINE DISTRIBUTION FROM SATELLITE REMOTELY SENSED DATA

Strategy

The purpose of this research is to develop the capability to measure or predict the oceanic thermohaline structure by means of satellite remote sensing. The ability to convert data to information has historically developed much slower than the improvement in data acquisition hardware. The emphasis of the parameter inference portion of this effort is on the extraction of useful information from existing sensors. No new hardware development is anticipated. Two different approaches will be pursued to reach the objectives of this program element:

- Direct Measurement Program. The Brillouin effect will be tested in the laboratory to see if changes in the Brillouin shift can be detected with sufficient sensitivity to be utilized as a remote sensing method. This is necessary because the application of pulsed techniques, which are necessary for ranging purposes, to Brillouin scattering is a unique approach. The method will then be tested in one of the large tanks or barge canals at NSTL to determine if changes can be measured as a function of depth. Assuming favorable results from these experiments a feasibility study utilizing the laser system and, e.g. CTD's, will be initiated. From these studies correlations between the remotely sensed frequency shift data and changes in temperature and salinity with depth can be made. Using this kind of ocean truth data for verification at a number of points an attempt will be made to chart where high density gradients exist. Assuming favorable results from these studies, a cooperative program will be established with NADC to build a state-of-the-art device using the techniques established in this program. During the full term of this program, channels of communication (visits, reports, seminars, and scientific publications) will be kept open to insure that no opportunity for cooperative studies is missed or no duplicative efforts exist.

- Parametric Inference Program. Optimal parameter quantification algorithms will benefit from an integrated multispectral and multisatellite approach. Research will involve visible, IR and microwave sensors on all available satellites. Initial work will be with the LANDSAT and NOAA satellites with the effort extending to SEASAT, DMSP and NIMBUS as this data becomes available. Where possible, programs will be accomplished by cooperative efforts, with NASA, NOAA, Coast Guard, and existing Navy funded remote sensing and oceanographic projects. Although the direct measurement and parametric inference approaches have been described separately here, it should be noted that these will be complimentary coordinated efforts. Satellite direct measurement is many years off so inference will have the quickest payoff. However, prototype laser systems could conceivably be used aboard aircraft as "ground truth" for satellite systems within a few years. The ability to convert data to information has historically developed much slower than improvement in data acquisition hardware. The emphasis of the parameter inference portion is on the extraction of useful information from existing sensors. No new hardware development is anticipated to implement this program.

Tactics

- FY-78
  - -- Provide detailed specifications and begin procurement of a spectrometer system.
  - -- Coordinate a short training course to familiarize scientists with currently available digital image analysis techniques.
  - -- Accept delivery of digital image analysis system.
  - -- Complete installation of laser equipment for laboratory studies.
  - -- Use LANDSAT data to demonstrate the utility of multispectral techniques for oceanographic applications.
  - -- Complete checkout and preliminary laboratory laser studies.
  - -- Conduct several aircraft/surface vessel missions (in cooperation with other groups) to acquire data for analysis of the boundary delineation and parameter measurement problems.
  - -- Analyze collected data from the laboratory laser studies and report on feasibility. Recommend changes in program plan.
  - -- Verify satellite temperature accuracy and develop a theoretical framework which employs the remote sensed sea surface temperature as input for the forecasting of the thermal structure.
- FY-79
  - -- Complete preliminary laser system field data collection.
  - -- Complete analysis of laboratory and field studies data.
  - -- Complete analysis and interpretation of laser system field data.
  - -- Develop a computer software system based on the theoretical temperature model developed in FY-78. The system will initially be checked out using existing climatological data.
  - -- Design and conduct a major oceanic field experiment (conceivably, employing SEASAT-A and DMSP satellites) for verification of both active and passive techniques developed to date.
  - -- In support of satellite data analysis, begin basic field research into the spectral scattering properties of various water types utilizing the spectrometer system from a ship or helicopter platform.
  - -- Expand the study from sea surface temperature into other parameters especially those available from the SEASAT-A microwave sensors. Wind vectors will be the highest priority parameter.
- FY-80
  - -- Continue to conduct several aircraft/surface vessel missions (in cooperation with other groups) to acquire data for analysis of the boundary delineation and parameter measurement problems.
  - -- Analyze the data from the above missions and report on feasibility. Recommend changes in program plan.

19. WATER VAPOR CORRECTIONS IN THE THERMAL IR

Strategy

The purpose of this research is to develop automated, objective techniques to correct thermal infrared observations from satellites for atmospheric contaminants in order to allow high resolution definition of sea surface temperatures to support oceanic thermohaline modelling.

Techniques and algorithms have been developed to identify IR samples which are cloud contaminated and to make corrections for atmospheric water vapor. These will be integrated into the system to fully automate the transformation of raw infrared and visible scanning radiometer data into quantitative sea surface temperature values, produce analyses based on these measurements, and prepare these data for input to related data bases.

Tactics

- FY-78
  - -- Convert and integrate algorithms to allow processing of NOAA satellite VHRR data for quantitative measures of sea surface temperature.
  - -- Collect a sample of VHRR data coincident with surface "truth" collection programs and evaluate the accuracy of satellite derived sea surface temperatures in cloudy atmospheres.
  - -- Develop techniques for calibrating and correcting data that will be forthcoming from the AVHRR sensor to be carried aboard the TIROS-N satellites.
- FY-79
  - -- Collect AVHRR data in association with an intensive ground-truth data collection program. The ground-truth data should include, in addition to ship SST measurements, extensive atmospheric measurements from aircraft and radiosonde balloons in order to allow verification of the satellite derived atmospheric corrections.
  - -- Perform detailed analyses of the data and evaluate the accuracy of the satellite derived SST data.
  - -- Convert the results of this data and analyses for use with DMSP Block 5D-2 Optical Line Scanner data.
- FY-80
  - -- Collect and process a sample of direct readout DMSP Block 5D-2 data in association with ground truth data.
  - -- Analyze and verify the SST retrieval algorithms on the DMSP Block 5D-2 data collected.
  - -- Plan and coordinate a test of the system in a Fleet exercise.

20. ADVANCED RETRIEVAL OF ATMOSPHERIC MASS AND MOISTURE PROFILES

Strategy

The purpose of this research is to develop improved techniques for deriving mass-moisture and mass-tendency information from satellite borne indirect sounders and convert these data into useful inputs to numerical models, define optimum relationships between mass-moisture structure parameters and the inherent information contained in indirect sounding measurements, and develop optimum methods for the extraction and conversion of these data into advanced numerical prediction models.

Tactics

- FY-78
  - -- Test and evaluate current retrieval technique on data from the DMSP Block 5-D sounders.
  - -- Explore techniques for incorporating information from multiple moisture channels into the retrieval technique.
  - -- Initiate development of techniques to optimally introduce derived information into numerical prediction models.
- FY-79
  - -- Explore techniques for incorporating microwave channels into the retrieval algorithms.
  - -- Test and evaluate retrieval algorithm on NIMBUS-F High Resolution Infrared Radiometer Spectrometer data.
  - -- Continue development of technique to optimally introduce derived information into numerical prediction models.
  - -- Convert retrieval algorithms to accommodate channels in the HIRS-2 instrument to be flown on TIROS-N.
  - -- Convert algorithms to accommodate new channels to be incorporated in the DMSP 5-D-2 sounder.
- FY-80
  - -- Perform comparative evaluations on the HIRS-2 and DMSP 5-D-2 sounder data.
  - -- Test and evaluate the impact of indirect sounding data on the accuracy of numerical prediction models.

21. REMOTE OCEAN SUBSURFACE TEMPERATURE PROFILER (ROSTEP)

Strategy

The purpose of this research is to determine the feasibility of remotely measuring the open ocean subsurface temperature profiles and develop a remote sensing capability that measures temperatures below the surface of the ocean. These measurements will provide quantitative data on air-sea energy exchanges which support meteorological and oceanographic prediction models and also as inputs for sound velocity calculations to predict performance of tactical and strategic acoustic weapons systems.

The approach envisioned is to conduct a system analysis for establishing system parameters of a model laser sensor in the visible region for operational measurement of subsurface ocean temperature profiles, utilizing the fact that the Raman spectra centroid shifts with the temperature of the medium. Then, data from field measurements will be utilized with the feasibility model sensor to define performance parameters for operational systems to meet Navy measurement requirements.

Tactics

- FY-78
  - Complete fabrication of optical components.
  - Fabricate electronic components.
  - Perform laboratory test of optical components and complete sensor.
  - Complete planning for field tests with NADC.
  - Begin field measurements from towers and ships.
- FY-79
  - Complete tests and analysis of tower and ship measurement data.
  - Install ROSTEP in NRL RP-3A 149670.
  - Begin aircraft field tests of ROSTEP.
  - Begin analysis of aircraft field measurements and evaluate performance of ROSTEP with NADC.
- FY-80
  - Complete aircraft field test measurements.
  - Complete analysis and evaluation of aircraft test data with NADC.
  - Make decision regarding sensor maturity for transition to 6.3- Advanced Development.
  - Develop data package for ROSTEP transition to 6.3- Advanced Development.

22. OCEANOGRAPHIC EXPLOITATION OF SATELLITE DATA

Strategy

The integration of the strategies and tactics from the prior program elements provides the ability to develop manuals and guides for Navy operational use of satellite data. The overall strategy for this effort is twofold. The first portion of the strategy is to develop general and regional guides for the tactical military oceanographic use of satellite data. The general guide would give examples of selected oceanographic phenomena and effects that can be delineated by DMSP, TIROS N, NOAA and world weather watch GOES satellites. Each guide would define and give examples of the critical ocean features of an ocean region that can be delineated by DMSP and other satellite data. The region covered by the first guide will be the Mediterranean and its adjacent seas and gulfs. The approach will be to derive the critical military information requirements that can be met by satellite data for general ocean areas and derive the same requirements tailored to selected ocean regions. Regional satellite data will be collected from in situ direct readout satellite field units to show the temporal and spacial distribution of the ocean features that furnish the needed information. Methods of computer manipulation of satellite data to better furnish this information will be explored and developed. The results will be published in a series of general and regional guides for tactical utilization. Although DMSP data will be stressed, other applicable satellite data will be used.

NEPRF has initiated a series entitled "DMSP Tactical Applications Guide Series, Volume II-Environmental Phenomena and Effects." A third volume on regional applications is to be a cooperative effort by NEPRF and NORDA, where NEPRF will be responsible for the meteorology and NORDA for the oceanography. The first regional guide will cover the Mediterranean and its adjacent seas and gulfs. The period to collect data for inclusion in Volume II will be three months with the volume ready for publication three months later. The period to collect the data for the third volume will be one year with the guide ready for publication six months later. The one year period will be necessary in order to accumulate sufficient data to derive seasonal variations in the Mediterranean area. During this period, satellite data from other regions will be collected and analyzed in order to expedite the production of guides for these regions if selected and approved.

During the production of the Mediterranean guide, Navy users and field activities in the Mediterranean region will be approached to derive the information which they believe to be most useful from satellite data. In addition, manipulative studies will be made of the data to derive methods of extracting information not apparent at this time. All available satellite data will be examined in addition to that of the DMSP to derive information for times or spectral ranges not available in the DMSP data.

The second portion of the strategy is to develop satellite and remote sensing analysis techniques for environmental monitoring applications. Experimental field and laboratory programs will be conducted in cooperation with other groups in the Navy, academic institutions, and various government agencies.

Tactics

- It is estimated that the first 15 months will be spent assembling the data for full seasonal coverage of the Mediterranean guide while simultaneously finishing Volume II. Final publication of Volume II will occur within 12 months, with the first guide of the third volume a year later.

- Techniques will be developed for the utilization of satellite data for environmental applications related to Naval operations, such as ocean dumping monitoring, protection of offshore assets, maritime inshore environmental quality, and deposition of dredge spoils. These applications will be pursued on a reimbursable basis with minor expenditures of base funding for development of data to demonstrate feasibility.

23. BATHYMETRY AND COASTAL TOPOGRAPHY

Strategy

The purpose of this research is to determine the optimum bandwidths, wavelengths, and orbital configuration for satellite multispectral scanning applications to inshore bathymetry of variously turbid waters.

High altitude aircraft will be used to fly a multispectral scanner modified to test variously filter controlled wavelengths and bandwidths over coastal waters of varying degrees of siltation and turbidity. These flights will be flown at select times of the day along specific tracks to differentiate sun angle and intensity attenuation.

Tactics

- FY-78
  - -- Modify the existing multichannel line scanner based on previous ONR research findings.
  - -- Enhance the computer model for handling and analyzing this data.
  - -- Begin flight tests with high altitude aircraft.
- FY-79. Continue flight tests with aircraft defining optimum bandwidths, wavelengths, and sun angles for variously turbid waters.
- FY-80
  - -- Continue flight test to determine the number of overpasses of an area required to obtain a 90% degree of probability of correct depth readings for water of varying current speeds.
  - -- Finalize the computer program and define the orbital frequency necessary for the operational system.

24. IDENTIFY, TRACK, AND PREDICT ICEBERG DRIFT

Strategy

The purpose of this research is to identify, track and predict iceberg drift using satellite and automated data processing techniques. There is a need for developing satellite capabilities that meet and improve upon current airborne techniques for locating and tracking icebergs and for predicting their drift. By conducting closely controlled and coordinated satellite, airborne, and ground truth measurement programs, the capabilities of current and proposed satellite systems can be determined for locating and tracking icebergs and for supplying information necessary for predicting their drift. Once the potential of each satellite system has been determined, the most promising systems will be studied for enhancement and automatic data processing capabilities which can be applied to automatically identifying icebergs, predicting their drift tract, and updating as additional information is supplied.

Tactics

- FY-78
  - -- Conduct a coordinated aircraft, DMSP, LANDSAT, and classified satellite evaluation field exercise. Select areas of probable large size and high number icebergs based on Coast Guard International Ice Patrol experience. Perform a comparative resolution capability evaluation of the satellites using aircraft data as "surface truth."
  - -- Complete an evaluation report of this exercise.
  - -- Initiate signal processing and interpretation techniques.
- FY-79
  - -- Evaluate SEASAT synthetic aperture radar data capabilities for sea ice and iceberg research. Compare SEASAT data with classified satellite data.
  - -- Conduct a coordinated aircraft, iceberg, SEASAT, and classified satellite experiment in Baffin Bay. Perform a feasibility study of size-determining capability of the highest resolution satellite system. Repetitive satellite data will be used to determine drift tract of select observable icebergs. Icebreakers will conduct ground truth measurements in conjunction with aircraft. Current measurements and meteorological data, accurate navigational fixes, and size measurements will be collected during these experiments.
- FY-80
  - -- Complete a technical report of the FY-79 mission.
  - -- Utilize state-of-the-art signal processing techniques to enhance the capabilities of selected satellite systems.
  - -- Develop drift models.

25. SATELLITE OBSERVATIONS TO SUPPORT ARCTIC ENVIRONMENTAL STUDIES AND ICE PREDICTION

Strategy

The purpose of this effort is to utilize satellite remote sensor observations and navigation and data relay capabilities to provide required time-space sea ice feature distribution and motion characteristics for use in Arctic environmental studies to support development of sea ice prediction models and near real-time ice prediction techniques.

Plans are to design and participate in the collection of coincident time-space sea ice data from satellite, airborne, and surface platforms. Capabilities to interpret satellite sensor sea ice data in terms useful to research investigation and operational objectives will be evaluated. Processing techniques to enhance and format data for user application will be developed. Satellite data buoy interrogation and data relay programs to track ice motion and receive related atmosphere and ocean parametric data will be generated. Emphasis will be on the marginal ice zones in support of ASW and mine warfare objectives.

Tactics

- FY-78
  - -- Design and participate in airborne and satellite coincident data collection programs.
  - -- Evaluate and develop satellite data interpretation capability.
  - -- Develop interactive techniques using softwave systems to enhance ice feature edges, remove raster bands, and study spectral response. Apply image color densitometer techniques to determine ice age and thickness and water feature distribution.
- FY-79
  - -- Extract and bank useful time-space parametric ice data.
  - -- Generate a sequential satellite data collection program over the ice covered Greenland Sea to classify ice forms and to monitor deformation and motion.
  - -- Design and participate in data collection from airborne and surface platforms coincidently with data collection from SEASAT.
  - -- Initiate data relay and ice floe tracking experiments in the Greenland Sea.
  - -- Generate experimental forecasting program with FLEWEAFAC and use satellite data to analyze the accuracy of the forecast.

26. SATELLITE REMOTE SENSING FOR SNOW/ICE COVER OVER LAND

Strategy

The purpose of this research is to develop and evaluate satellite remote sensing techniques in order to identify, measure, and discriminate physical parameters of snow/ice cover over land in the polar regions. The parameters will include snow/ice cover areas, density, thickness, surface roughness, liquid water content, albedo, and surface temperature. This will be performed by carrying out ground truth investigations with the cooperation of other organizations and utilizing multi-sensor satellite data and man-machine interactive analysis techniques. The transfer mechanisms of mass, energy, and momentum for air/snow/ice land layers will be investigated and models will be developed for the prediction of the temporal and spatial variations of snow/ice cover over land.

Tactics

- FY-78
  - -- Participate and perform ground truth investigations for SEASAT with the cooperation of the Center for Cold Ocean Resources Engineering (C-CORE) and the Memorial University of Newfoundland. Initiate a study of the transfer mechanisms of mass, energy, and momentum over snow/ice cover in relation to the remote sensing measurements. Emphasis will be on snow and ice studies using the SEASAT synthetic aperture radar.
  - -- Plan and perform ground truth investigations for satellites such as DMSP, TIROS-N, and LANDSAT utilizing the facilities of the Naval Arctic Research Laboratory (NARL). The main objective of these investigations will be to determine the capabilities of the multi-sensor systems to identify and discriminate snow and ice parameters in the visual and IR spectral ranges.
  - -- Develop identification and interpretation techniques for snow/ice density, thickness, liquid water content, albedo, and surface temperature by visual and IR sensors of DMSP, TIROS-N and LANDSAT C satellites.
- FY-79
  - -- Investigate and evaluate the potential capabilities to measure and discriminate snow/ice area distribution and density, thickness, surface roughness and liquid water content using the synthetic aperture radar and the scanning multichannel microwave radiometer systems on SEASAT A.
  - -- Investigate and evaluate the capability to measure the snow/ice cover area and liquid water content using the passive microwave systems on NIMBUS-G.
  - -- Perform ground truth investigations for the scanning multi-channel microwave radiometer at NARL.

27. SATELLITE ALTIMETER OCEANOGRAPHIC ANALYSIS

Strategy

Precise determination of the height of the geoid is essential for finding the deflection of the vertical for strategic applications. Further, the difference between true geoid height and measured sea height at a given location is a function of the oceanographic effects of geostrophic currents, ocean tides and water mass anomalies, all of which are important constituents of the general ocean circulation. This effort will use SEASAT precision altimeter data with measured surface gravity data to determine the topography of the geoid and the associated oceanographic features.

SEASAT altimeter measurements of sea surface height will be used to map the geoid, isolate geoid anomalies, and interpret them with density models of the earth for prediction of gravity anomalies in remote oceanic regions. Individual residuals of sea surface heights from geoidal heights will be compared with measured geotrophic currents. Tidal constituents will be identified and subsurface thermal feature identification will be attempted for rings and eddies.

Tactics

- FY-78
  - -- Calculate gravity averages from ship data and determine the detailed gravimetric geoid.
  - -- Compare this information with altimeter data in order to evaluate altimeter performance and determine deviations of the sea surface from the geoid.
- FY-79
  - -- Isolate geoid anomalies with filtering techniques. Model anomalies with direct and inverse techniques.
  - -- Compare oceanographic residuals of altimeter data with hydrographic station and XBT data.

28. MULTI-SPECTRAL REMOTE SENSING OF ATMOSPHERIC CONSTITUENTS

Strategy

The purpose of this research is to develop objective techniques to derive environmental information relevant to Navy requirements from multi-channel passive microwave data into geophysical units, evaluate relationships using real data from SEASAT, NIMBUS-G, and DMSP satellites, and relate the output parameters to Navy operational and environmental support requirements.

Tactics

- FY-78
  - -- Establish response and resolution characteristics of the 5-channel passive microwave radiometer to be flown on NIMBUS-G and SEASAT-A satellites and evaluate their potential for defining cloud liquid water content.

-- Perform case studies to evaluate the accuracy to which the vertical profile of divergence associated with tropical storms can be inferred from microwave radiometer data.

- FY-79

  -- Collect, analyze and interpret SEASAT and NIMBUS-G data in terms of atmospheric cloud liquid water content and water vapor content.

  -- Perform additional studies to evaluate the potential of deriving divergence fields from multi-channel microwave radiometer data.

  -- Initiate work on inversion techniques for use with the ROMS instrument to be flown on the DMSP STP vehicle in 1981.

  -- Initiate work on conversion of liquid water content and water vapor information to parameters of direct use as tactical indices in electrooptical and electromagnetic system performance criteria.

- FY-80

  -- Continue work on inversion techniques for the ROMS instrument.

  -- Perform simulated studies using divergence fields inferred from microwave radiometer data, rotational components of the wind field derived from Geo-stationary satellite data, and vertical temperature and moisture fields derived from indirect sounders as inputs to fine-mesh numerical tropical storm models.

  -- Continue work on the conversion of liquid water content and water vapor information to parameters of direct use as tactical indices.

- FY-81

  -- Collect, analyze and evaluate data from the ROMS Space Test Program instrument for the definition of detectable parameters.

  -- Continue work on the conversion of the microwave radiometer to tactical indices.

  -- Continue work on the impact of satellite data on the accuracy of numerical tropical storm predictions.

29. ADVANCED SENSORS FOR ATMOSPHERIC TEMPERATURE AND MOISTURE PROFILES

Strategy

The basic strategy is to improve the basic knowledge of the technology in the areas of detector materials and sensitivity, filter bandpass, and interferometer and neterodyne capability in order to permit the development of advanced atmospheric indirect sounders for deployment in the 1985-90 timeframe.

The approach envisioned is to survey projected technological developments to ascertain the areas of highest potential technological advances that can be expected in the next decade. Those areas will be pursued that offer the highest potential for producing a multi-channel indirect sounder which will provide spatial, vertical, and absolute resolution of atmospheric state parameters required to satisfy Navy environmental requirements. Channel bandwidths between 0.5-4.0 wavenumbers or less in the water vapor, carbon dioxide, and oxygen absorption bands are the design goals.

Tactics

- FY-78
  - -- Perform a survey of current state-of-the-art and future potential of optical technology relevant to the infrared portion of the electromagnetic spectrum. This survey will include detectors, filters, advanced interferometers, transmission function accuracy in water vapor, carbon dioxide and ozone absorption bands, and mathematical retrieval techniques.
  - -- Perform a similar study for passive microwave technology.
- FY-79
  - -- Based on the results of the survey of optical technology, write specifications for the development of required technological improvements in order to allow development of an advanced indirect sounder for the 1985-90 timeframe.
  - -- Based on the results of the passive microwave technology study, write specifications for the development of an advanced microwave sounder for the 1985-90 timeframe.
  - -- Let basic research contracts to develop the required technology developed in the above two FY-79 items.
- FY-80
  - -- Continue development of the required technology in the third item of FY-79.
  - -- Design and fabricate breadboard models of advanced indirect sounders.
- FY-81
  - -- Fly a prototype instrument on a space test vehicle.
  - -- Transition efforts to 6.2-Exploratory Development or 6.3-Advanced Development areas.

30. POSITION DETERMINATION OF SATELLITE REMOTE SENSOR DATA

Strategy

The purpose of this effort is to develop advanced algorithms capable of more precise positioning oceanographic, atmospheric and cartographic satellite remote sensor data. The effort will be directed toward improving the relative positional accuracy of significant parameters as well as their absolute position on the earth's surface. The rationale, methodology, software and data reduction procedures for fitting the satellite data to an earth reference cartesian coordinate system will be developed and perfected. Navigation smoothing and data analysis models will be developed to help determine and reduce positioning error sources. These models will be designed so as to most nearly achieve the horizontal and vertical measurement accuracies set forth for the various parameters in the requirements.

The general approach will be to develop accurate digital data bases to use as a basis for positioning the desired satellite data. A preliminary positioning of the observed data on the data base will be accomplished using predicted and observed satellite ephemerides. A more precise fit will then be statistically computed by incorporating available surface datum with correction factors derived from the navigation smoothing and data analysis models. As the volume of redundant data increases it will be used to continually update and improve the original data base. Relative positional accuracy will also be increased using statistical smoothing and best fit techniques.

Tactics

- FY-78
  - -- Formulate the rationale and methodology for developing accurate digital data bases to be used as a basis for positioning the satellite data.
  - -- Develop and test the software to generate these data bases.
  - -- Investigate methods of predicting and computing satellite ephemerides and select and incorporate the ones most suitable into the system.
- FY-79
  - -- Develop and test navigation smoothing and data analysis models designed to determine the source of errors and the reduction of these horizontal and vertical positioning errors.
  - -- Develop and perfect techniques to statistically computer a best fit for the satellite data to available surface datum by incorporating the corrections desired for the navigation smoothing models.

- FY-80

  -- Develop software to enable the incorporation of redundant data into the data programs.

  -- Once perfected, test the entire procedure to insure that the stated accuracy requirements can be satisfied.

  -- Prepare a complete set of documentation to accompany the programs.

31. INTERACTIVE GRAPHICS DISPLAY FOR NAVY ENVIRONMENTAL REQUIREMENTS

Strategy

The purpose of this research is to develop hardware and software interactive graphics display system for use at all levels of the Navy Environmental Support System. The system will provide for ingestion, processing, display, and extraction of information from in situ and remotely collected environmental polar and geosynechronous orbiting satellites. Additional attention will be devoted toward interfacing this type of system with command and control and other operational systems.

Based on the feasibility model display device currently operating at NEPRF, it is planned to develop an upgraded system taking advantage of the rapidly expanding minicomputer technology. A flexible system will be developed for acquiring, processing, displaying and extracting information from operational satellites such as DMSP, TIROS-N, GOES, and SEASAT. The software development will be modular to allow interchangeable application of algorithms to data from different satellites.

Tactics

- FY-77

  -- Continue processing and development of software for DMSP and mapped polar sterographic data.

  -- Continue software development to interface GOES Acquisition and Data Handling System.

  -- Continue software development to allow processing of satellite data with FFT board.

- FY-78

  -- Upgrade display device minicomputers to the NOVA Eclipse and adapt interface electronics.

  -- Complete software for processing DMSP and mapped polar stereographic satellite data.

-- Complete software for analysis of satellite data using FFT board.

-- Implement navigation software package for the GOES satellite on the display device.

-- Commence test and evaluation of automated cloud tracking system using realtime GOES data.

-- Implement software to convert cloud motion vector end points from image coordinates to earth located coordinates.

-- Based on the SMQ-6 antenna system upgrade, design a data ingestion, processing, and storage system that will allow full digital processing of TIROS-N direct readout APT data.

-- Design a system upgrade that will allow acquisition of TIROS-N and DMSP high resolution direct readout data.

-- Procure the antenna and pedistal and let contracts for the above two items.

- FY-79

-- Implement objective analysis program on display device.

-- Implement ephemeris program for polar orbiting satellites on computers.

-- Convert and write a general purpose program to convert satellite data from scanline coordinates to polar stereographic and mercator projections.

-- Upgrade SST extraction program and analysis modules.

-- Implement other applications software and algorithms as they become available from other efforts.

-- Install system and checkout at land research facility.

-- Develop and convert software for calibration, earth location, and enhancement of the data on the microprocessor system.

- FY-80

-- Commence work on transforming environmental data into tactically-specific indices.

-- Perform a realtime demonstration with FNWC to provide cloud motion data as an input to numerical models.

-- Develop software to allow ingestion of locally acquired conventional environmental observations.

-- Integrate the system using locally acquired direct readout satellite data.

- FY-81

  -- Install feasibility model system on an operating ship and evaluate in a Navy exercise.

  -- Design a prototype system for Operation Evaluation using state-of-the-art technology.

  -- Continue work on implementation of applications algorithms.

  -- Continue work on transformation of environmental data to tactically-specific indices.

  -- Write specifications for a prototype system for test and evaluation at a Fleet Weather Central.

- FY-82

  -- Procure prototype system.

  -- Convert all software to the prototype system and optimize for operational use.

  -- Install the prototype at Fleet Weather Central.

32. SYSTEMS UPGRADE FOR THE SMQ-10 AND TMQ-29

Strategy

The basic strategy is to procure prototype hardware and upgrade and develop software modules for the SMQ-10 and the TMQ-29 to function as self-contained environmental support centers. Utilizing solid state, microprocessor, integrated circuit, and CRT technology, upgrade the SMQ-10 and TMQ-29 systems to allow full interactive graphics manipulation of environmental data. Software modules will be developed to allow efficient extraction of tactically significant environmental parameters. The feasibility of interfacing this system directly with weapons systems for automatic input of environmental factors will be explored.

Tactics

- FY-78

  -- Design and procure an interactive, softcopy display device to be integrated into the SMQ-10 and TMQ-29 simulator systems.

  -- Implement existing SMQ-10 operating and applications programs and become familiar with their operation.

- FY-79

  -- Initiate conversion of special purpose applications software to the SMQ-10 simulator.

-- Modify and upgrade the DATACRAFT-5 operating system software to allow efficient expansion.

-- Initiate development of new applications software.

- FY-80

  -- Continue conversion of existing applications software.

  -- Continue development of new applications software.

  -- Initiate development of software to convert environmental parameters into tactical indices.

- FY-81

  -- Continue development of new applications software.

  -- Continue development of software to convert environmental parameters into tactical indices.

  -- Explore feasibility of interfacing upgraded SMQ-10 system directly into weapons systems.

- FY-82

  -- Demonstrate the utility of the system in a simulated operational environment.

  -- Write specifications for production retrofit of operational SMQ-10 and TMQ-29 systems.